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FINAL REPORT

For

AUTOMATIC STEREO CORRELATOR

SC-1305

"Construction of Breadboard System of an Automatic Stereo Correlator and Evaluation of the Performance Capabilities of such a System."

Period Covered:	July 1964 - July 1965
Date:	23 July 1965
Job No.:	SC-1305
Document No.:	OD-130

<u>TASK OBJECTIVE</u>

To manufacture a breadboard and to conduct sufficient tests to determine the performance capabilities inherent in a system of automatic stereo correlation as described in the 552 MSC proposal.

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I

THE AUTOMATIC STEREO CORRELATION SYSTEM

[redacted] proposed a system of Automatic Stereo Correlation as a product improvement for the Model 552 Viewer* in February 1964. The proposed system would be completely automatic once the operator made the initial stereo setting. Automatic correction would be provided for displacement errors in the X and Y axes, errors in angular position and differences in magnification. In addition, it was proposed to control the intensity of the light sources so that the left and right images were observed at equal levels of illumination. Correction for anamorphic error, a logical extension of the system proposed for magnification error correction, was proposed in March 1965. If the images have no contrast such as water images, the automatic system would not operate and the system would revert to normal control for the X and Y carriages, but magnification and angular adjustments would remain at their last setting. The reversion of the X and Y automatic tracking system to manual control is accomplished with a suitable time delay so that in the event of momentary loss of signal information, such as that caused by a cloud, the system will continue to track at the last setting until after the delay and be able to control automatic tracking when the signal is again present. 25X1

* Refer to Figure 1 for the optical schematic of the 552 and Figure 5 for the application of the Automatic Stereo Correlation System to a 552 type viewer.

II
PRINCIPLE OF OPERATION
OF SCANNER

1) X AXIS

Figure 2 illustrates the principle of operation of the scanner. As shown, two (2) slits are provided so that the image of the right frame is scanned in synchronism with that of the left frame. These images are relayed from the fiber optics end at the eyepiece assembly. Consequently, the system should maintain these two (2) images so that they are essentially the same. It should be realized, however, that if there are any height differences, then the two (2) images cannot be made identical. In this case, the average center of one image is made to correspond to the average center of the second image.

The operation of the system is based on the utilization of two (2) slits scanning both frames simultaneously in synchronism. Two (2) photomultipliers are provided for photodetection of the light level of the slits. As shown in Figure 2(I) the two images are in correspondence. In addition, the relationship of the two slits is such that the slit of image b is leading in phase that of a. In other words, the slit of b is slightly to the right of a.

For simplicity of analysis, assume that the image is a dot in the center. Then the signals developed by the scanning slits are shown. The difference of these signals is then developed by a difference amplifier. In addition, the amplitude of that difference $\overline{(a-b)}$ is computed. The amplitude of $\overline{(a-b)}$ is determined by changing the negative portion of the signal (a-b) to a positive value. Now, when the slit of image b' is lagging that of a', as

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shown in the lower right of Figure 2(II), then the slit of b' is slightly to the right of a'. The resultant signals of a', b', (a'-b') and $\overline{(a'-b')}$ are as shown.

It may be noted that in the case mentioned above, $\overline{(a-b)}$ for a leading slit phase is the same as $\overline{(a'-b')}$ for a lagging phase, or $\overline{(a-b)} - \overline{(a'-b')} = 0$.

However, let us consider the case when the object in (b) is to the right of where it should be, as shown in Sections IV and V of Figure 2. Consequently, the two images are not in correspondence. It may be obvious that now that the difference $\overline{(a-b)}$ has decreased for the leading phase of the scanning slit, and has increased for the lagging phase. Consequently, if $\overline{(a-b)}$ leading is compared to $\overline{(a'-b')}$ lagging, then an error signal is developed corresponding to offset in the relative position of the object; consequently, $\overline{(a-b)} - \overline{(a'-b')}$ is negative as indicated in Section VI of Figure 2.

It may be noted that if the error of position of the object is reversed, as shown in Figure 2, (Section VII and VIII) then the difference $\overline{(a-b)}$ has increased for the leading phase, and has decreased for $\overline{(a'-b')}$ the lagging phase, then $\overline{(a-b)} - \overline{(a'-b')}$ is positive. Consequently, by comparing $\overline{(a-b)}$ leading to $\overline{(a'-b')}$ lagging, the polarity of the signal determines whether the error is to the right or to the left.

The operation of the system integrates the error $\overline{(a-b)}$ lead $- \overline{(a'-b')}$ lag. This integration is achieved by an R-C network, which averages the amplitude of the error. This DC signal is applied to a standard DC servo system, where the speed of the correction is dependent on the amplitude of the signal, and the direction of drive is dependent on polarity of the error signal.

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PRINCIPLE OF OPERATION (Y-AXIS)

2) Y ERROR

As shown in Figure 3, (left column) the slits for the Y axis are designed in a similar manner to the X axis, except that the direction of scan is now along the Y axis. Two (2) scans are made, one with the slit b leading, and another scan with the slit b lagging. The error signal is then determined by $\overline{(a-b)}$ $-\overline{(a'-b')}$.

3) θ ERROR

The operation of the orientation detection is provided in a similar manner to the Y axis scan. However, the scanning of the slits is achieved along the Y axis, but the phase leading and phase lagging signals are developed by rotating the (b) slit in clockwise and counterclockwise direction. The $\overline{(a-b)}$ lead is then compared to $\overline{(a'-b')}$ lag to result in the servo error signal.

4) (M) ERROR

The magnification error signals are developed by slits scanning in the Y axis. However, these slits in the b frame are placed slightly out of focus, beyond the image plane as in Figure 3, (right hand column). The magnification is increased slightly. The scan shown in lower right Figure 3 is developed when the slit in the b frame is closer to the focusing lens, thus with slightly less magnification. The signal $\overline{(a-b)}$ (higher magnification) is compared to $\overline{(a'-b')}$ (lower magnification) to result in a servo error signal.

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5) ANAMORPHIC ERROR *

The anamorphic error signals are developed in the same manner as the magnification error signal except that the direction of scan is now along the X axis. Two scans are made, one with slightly more magnification in the b frame. The signal $\overline{a-b}$ high magnification is compared to $\overline{a'-b'}$ (lower magnification to result in a servo error signal.

6) THE AVERAGING NATURE OF THE SYSTEM

The system design described has an advantage in that it is an averaging sensor, whereby the images from the right and left frames do not have to be identical. Thus, if the images observed have appreciable height, the two images are not the same. The system averages by scanning so that it offsets in one direction (Δ) and the other direction ($-\Delta$). It then maintains the errors for Δ and $-\Delta$ the same. Consequently, if the contrast of the two images are not the same, there is always an optimum position where Δ and $-\Delta$ are equal, even though the value of this Δ may be relatively high. It may also be concluded that any distortion in one frame relative to the other does not cause malfunction of the system, due to the averaging feature described above.

* Proposed extension of the magnification error correction system.

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[redacted]

III
THE BREADBOARD SCAN SYSTEM

1) BREADBOARD SIMPLIFICATION

The breadboard system is similar to the basic system. By restricting the maximum object size to about 1 inch square and making the left side optical system solely manual, considerable simplification is achieved in the breadboard model. There are no X and Y axis memory features.

2) LEFT SIDE SYSTEM

The left side system consisted of a film holder with manual X, Y motion and illuminating light. An optical system incorporating a fiber optic cable transmits the image to a beam splitter which passes the image to the left eyepiece and to the scanning disc.

3) RIGHT SIDE SYSTEM

The right side system contains a motorized rotateable film holder and an optical system incorporating a motorized zoom lens mounted on a carriage having motorized X and Y drives. The optical system transmits the image to a beam splitter. The beam splitter passes the image to the right eyepiece and to the scanning disc. The scanning disc and the eyepieces are both mounted on the same motorized X, Y carriage used for the right channel. The illumination source of the right channel is controlled by an automatic solid state dimmer.

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4) COMMON FEATURES

The left and right images projected on the disc are scanned by slits, as described in Section III part 5. The images scanned by the slits are projected on the cathodes of two photomultipliers. Lenses are used to defocus the images on the photomultiplier in order to eliminate the effects of variations of the photo cathodes sensitivity. Five (5) photo diodes and synchronizing slits are used to synchronize the scanning disc and the electronic circuitry.

5) ERROR DETECTION SLITS

The images from the right and left formats are rotated by two dove prisms so that the images along the X and Y axis when focused on the scanning disc, conform to the X and Y slit directions of the scanning disc, as shown in Figure 4. As noted, slits are provided to achieve the scanning motions previously described. However, the slits are located at 45 degrees from the film axis in order to achieve the X and Y scans. In position 1, Figure 4, the slit travels across the Y direction in both the right and left format. The slit of the right format is shown at the center of the optical axis while the slit of the left format, 1; is offset by Y_1. Ninety (90°) degrees after this scan is made the slits in position 6 and 6' are in operation. The offset in the Y axis is now ΔY_2. Thus, two (2) offsets are utilized (ΔY_1 and ΔY_2) which correspond to two different fields of view. These two offsets present error signals with an offset in one direction. However, as the disc rotates 180 degrees, the slit 1' interchanges its position with slit 1. In this manner, the ΔY_1 and ΔY_2 are also reversed. Consequently, during one resolution four scans, ΔY_1, ΔY_2, $-\Delta Y_1$ and $-\Delta Y_2$, are obtained. The error signal developed is computed based on $\Delta Y_2 + \Delta Y_{2'}$, and $-\Delta Y_1 - \Delta Y_1$.

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After the Y direction scan at the 1, 1', 6 and 6' slits are scanned. The anamorphic correction slits shown in Figure 4, slits 2, 2', 7, and 7' are referenced only. Slits 3, 3' and 8, 8' provide scanning in the X direction. In this case, position 3 is displaced by ΔX_1 and position 8 by ΔX_2. After 180 degrees rotation, the displacement will reverse. The four resultant scans are ΔX_1, ΔX_2, $-\Delta X_1$ and $-\Delta X_2$.

- The orientation scan is achieved by slits 4 and 9. The actual scan motion is made in the Y axis; however, there is a slight tilt, $\Delta \Theta$, and $\Delta \Theta_2$ provided in slits 4 and 9. Again, when the positions are reversed by 180 degrees, the orientation error is reversed. Consequently, four (4) scans are developed, $\Delta \Theta$, $\Delta \Theta_2$, $-\Delta \Theta$, and $-\Delta \Theta_2$.

The magnification scan is achieved by slits 5 and 10 where slit 5 is across the right format and slit 5' is across the left format. The slits in positions 5 and 10 results in increased magnification through the use of lenses mounted over the slits. These lenses produce a change of magnification of ΔM_1 and ΔM_2 respectively. Now, after a 180 degree reversal, the left format will be increased in magnification while the right format remains the same as the other slits. This reversal of increase in magnification from the right to the left results in an error signal similar to that shown in Figure 2. Consequently, four (4) scans are provided: ΔM_1, ΔM_2, $-\Delta M_1$ and $-\Delta M_2$.

As described previously, the same scanning disc is utilized to develop errors for four (4) servo systems, X, Y, M and Θ. This time sharing of the photomultipliers and the optics results in a unique system having a high degree of simplicity and reliability.

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6) THE SYNCHRONIZING SLITS

In order to allow this time sharing, an electronic switch is provided. This is achieved simply by utilizing 16 synchronizing slits located on the scanning disc and a 180 degree sense determining shutter, as shown in Figure 4. Five (5) light sources illuminate these slits from one side. On the other side, four photo diodes are located radially so that the light from one of the four quartets of synchronizing slits corresponding to the four error sensors, Y, X, Θ and M will be actuated at one time and a fifth photo diode is actuated by the 180 degree sense shutter. The block diagram, Figure 6, illustrates the utilization of each sensor to actuate consecutively X, Θ, M and Y, -X, -Θ, -M and -Y.

7) THE SCAN DRIVE

The scanning disc is rotated at approximately 10 revolutions per second by a DC gear motor driven by a solid state speed control.

IV
OPTICAL DETAILS OF BREADBOARD

1) <u>THE LEFT SIDE OPTICAL PATH</u>

The left side optical path consists of the following 14 elements:

a) A film holder consisting of a modified microscope stage which provides manual X and Y axis adjustment.

b) An objective lens mounted in a microscope barrel.

c) A fiber optic cable which transmits the image.

d) A field lens.

e) A diaphragm.

f) A dove prism to orient the image for proper scanning.

g) A beam splitter.

<u>BEAM SPLITTER PATH 1</u>

h) The scanning disc.

i) A lens.

j) A photomultiplier.

<u>BEAM SPLITTER PATH 2</u>

k) A dove prism to orient the image for viewing.

l & m) A pair of mirrors.

n) An eyepiece.

[redacted]

2) THE RIGHT SIDE OPTICAL PATH

The right side optical path consists of the following elements:

a) A motorized rotateable film holder mounted on a motorized X, Y carriage.

b) An objective lens mounted in a microscope barrel.

c) A motorized zoom lens.

d) A 45 degree mirror.

e) A field lens.

g) A colimating lens.

h) A diaphragm.

i) A dove prism to orient the image for proper scanning.

j) A beam splitter.

BEAM SPLITTER PATH 1

k) The scanning disc.

l) A lens.

m) A photomultiplier

BEAM SPLITTER PATH 2

n) A dove prism to orient the image for viewing.

o & p) A pair of mirrors.

q) An eyepiece.

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V
THE BREADBOARD ELECTRONIC SYSTEM

1) SCAN DRIVE AND SYNCHRONIZATION

The block diagram, Figure 6, shows the general operation of the system in the automatic mode.

A speed controlled DC motor is used to rotate the scanning disc at approximately ten (10) revolutions per second. During each complete scan, sixteen (16) selector gate signals and one (1) sense gate signal are provided by the sensing photo diodes. These provide sixteen (16) selection intervals correspond to a left and right side look at each of the two pairs of slits utilized for each of the four error channels.

2) PHOTOMULTIPLIERS AND PREAMPLIFIERS

The photomultipliers are RCA type 1P21; these are selected due to their low noise level and high sensitivity relative to their size. A 500 volt DC power supply is provided with a regualtion better than 1/2%, to maintain the electronic gain of the photomultiplier essentially constant. The preamplifiers are standard transistorized amplifier modules. They have an essentially flat response up to 200,000 cps. As used, the output of the preamplifier is a low impedance signal, allowing the use of an eight foot cable between the preamplifiers at the eyepiece assembly and the electronic rack.

3) THE MULTIPLEXED SYSTEM

The outputs of the preamplifiers are applied to a difference amplifier. If the signal from the left frame is (a) and the right frame signal is (b), then the output is (a-b) = D. An emitter follower buffer amplifier is used to apply the signal D to a signal to amplitude converter which is used to reverse the negative portion of the signal, resulting in $\bar{D} = \overline{(a-b)}$. The emitter follower is used in order to minimize the distortion due to the inherent non-linear input impedance of the signal to amplitude converter.

4) THE ELECTRONIC SWITCH AND ERROR DETECTION SYSTEM

The output $\bar{D}$ is applied to an electronic switch, which is actuated by the gating photo diodes. The coincidence of a sense gate signal and a selector gate signal are required to enable the output $\bar{D}$ to be distributed to the proper integrator. Thus, when an X scan is performed, an X selector gate signal and a 0 degree sense gating signal enable the signal $\bar{D}$ to be distributed to the X integrator, and when ΔX scan is performed an X selector gate signal and a 180 degree sense gating signal, generated by an inverter amplifier, enable the signal $\bar{D}$ to be distributed to the ΔX integrator.

The outputs of the X and ΔX integrators are subtracted by a low-drift modular difference amplifier giving a resultant output of $\overline{a-b} - \overline{a'-b'}$ which represents the servo error signal.

5) THE SERVO DRIVE

The four correction axes utilize 10 watt two-phase 60 cycle servo motors equipped with appropriate gear heads. Standard chopper input vacuum tube servo power amplifiers are used to drive the motors.

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6) THE ILLUMINATION CONTROL

The illumination control system is operated by the difference amplifier D_2 after preamplification and integration. Thus, if the illumination level is the same for the right and left frames, the average DC level of the right and left frames are equal, resulting in D = zero. Any error in the average value of D is applied to a solid state dimmer amplifier, which increases or decreases the illumination of one of the channels to make it equal to the other.

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VI

BREADBOARD PERFORMANCE

1) OPTICS

The performance of the optical system has been basically satisfactory. There are three areas where improvements could be made. The first is difficulty in centering the leads and lags of the slit shutters, especially the alignment of two pairs of slits for each error function. The second difficulty experienced is the lack of rigidity in the photomultiplier mount. The third is the limited motion that can be made before image clipping takes place. The first difficulty would be alleviated if provisions were made to permit the use of a simple alignment tool. The second difficulty would be eliminated if the photomultiplier tubes themselves were clamped rather than the sockets being held rigid. The use of larger size optics would easily overcome the third difficulty.

2) ELECTRONICS

The performance of the electronic system has been generally satisfactory with the sole exception of difficulty in obtaining good balanced output signals at low levels of input to the signal-to-amplitude converter. The present design consists of two PNP silicon common emitter class B amplifiers sharing a common load resistor. A degree of forward bias is applied to reduce threshold distortion. If the system were designed to use NPN silicon transistors designed especially for good β at low levels and with more uniform threshold characteristics, and if some degree of isolation would be imployed in the load circuit, much better performance could be achieved. Another approach using a single light emitting diode, such as a gallium arsenide diode biased with sufficient DC to avoid threshold effects, and optically coupled to a silicon photo diode would avoid both the balance problem and the threshold difficulty.

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A low priority was given to the intensity control system since its operation is not essential for demonstrating the scan principal, therefore, some minor redesign of this system is still required at this time.

Despite the limitations imposed by the present optical and electronic system difficulties, the breadboard is capable of automatic stereo correlation of simple images to accuracies better than .005 inches after initial manual stereo correlation is made. Detailed quantitative test results are given in Section VIII of this report.

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VII

CONCLUSIONS

The SC-1305 breadboard demonstrates the soundness of the scan principle involved and the relative ease of its implementation.

The breadboard design has also proved that the use of a fiber optic cable with an image enhancing system introduces no difficulties, and, therefore, that the principle is adaptable to a 552 type viewer. The system was made to track a simple "L" shaped target on all four axis simultaneously. One and two axis tracking was done using selected simple photographic images with the loss of signal information at low levels preventing automatic stereo correlation of four axis simultaneously.

Limitations of signal level imposed by the signal to amplitude converter has been the chief deterent to the use of the system with more complex targets.

This is an area where a small amount of further development along either of the two lines suggested in Section VI could bring greatly improved results.

VII
TEST RESULTS

1) SYSTEM PARAMETERS

The accompanying curves show the system performance in terms of millivolts output from the difference amplifiers for errors of the right side object in X and Y displacements in Θ rotation and in M magnification. Obviously, the actual position errors and sensitivity of the system does, from this point on, depend on the gain of the servo power amplifiers, the motors starting voltages, and the system friction. The system sensitivity of the breadboard was such that 1 to 3 millivolts of signal into the servo power amplifiers would cause the motor to drive. It would be simple to increase this. Residual voltage at null across the motors control phase were 2 to 3 volts RMS, and 4 or 5 volts RMS was the voltage when the motors started to drive. The targets for these curves were clear "L" shaped images on a black background. Their sizes were .08 inches in height by .06 inches in width, and .013 inches thick. The magnification from film to scan disc plane was three, 3X. The slit widths of the shutters were set at about .01 inches. A discrimination between X and Y movements of better than 5 to 1 was easily achieved.

2) X AXIS

Figure 7 shows the X axis response with fiber optic cable and image enhancer. The sensitivity about null is 2 millivolts for .001 inches displacement. At the nominal system sensitivity of 2 millivolts to start the servo motor, the breadboard responds to displacements of .001 inches. Allowing a safety margin of 4 millivolts from the minimum and maximum outputs, the system will track from approximately -.03 inches to +.018 inches, or for about .048 inches in the X direction where the target itself is only .06 inches.

Figure 8 shows the X axis without the fiber optic cable and, therefore, at a higher light level. The sensitivity around null is 4 millivolts per .001 inches, or twice as sensitive. It should be noted that the tracking range is .05 inches, or about the same.

Figure 9 shows the X axis without the fiber optic cable at a lower light level. Here the loss of information due to the action of the signal to amplitude converter is apparent.

It can be seen that the prime effect of the fiber optic cable was to somewhat reduce the sensitivity by lowering the image brightness. With a more linear signal to amplitude converter this effect would be reduced. The importance of good linearity of the signal to amplitude converter can be easily seen by comparing the three curves.

3) <u>Y AXIS</u>

The results with the image enhancer, Figure 10, shows the effects of some slit misalignment. The system would operate from -.015 to +.015 inches, or .03 out of an image of 0.08 inches with a sensitivity of 3 millivolts per .001 inches. Figure 11 shows much better adjustment. Tracking is good here for about .04 inches, and the sensitivity is 1.6 millivolts per .001 inches. Note the sensitivity is less but the null is better defined. Figure 12 shows the effect of low light level. Tracking is good for .045 inches, but the sensitivity is only 0.4 millivolts per .001 inches, and it would take an error of .005 inches before the motor would drive.

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4) **Θ AXIS**

Figures 13, 14 and 15 show the Θ axis. Sensitivity with the image enhancer was poor, .2 millivolts per degree with a broad null. Without the fiber optics, 4 millivolts per degree sensitivity was achieved at high illumination, and 2 millivolts per degree at low levels of illumination. Due to shifts in the X and Y positions, because the axis of rotation did not correspond to the optical axis of the objective lens, the curves show a degree of distortion. It can be concluded that the breadboard system could correct for at least ± 6 degrees and possibly as much as ± 13 degree rotational errors. Adjustment of this system is somewhat difficult. More sensitivity could probably be achieved with better adjustment.

5) **M AXIS**

Figure 16 shows a test on the M axis at low levels. Due to optical interference caused by the lens mounts on the scanning disc and a generally difficult adjustment, little data was taken. The M scale shown is arbitrary, only roughly corresponding to changes in ratio of magnification. It can be seen that changes of 10% in magnification produces a 3 millivolt change in error signal output. This could also probably be made more sensitive with better adjustment.

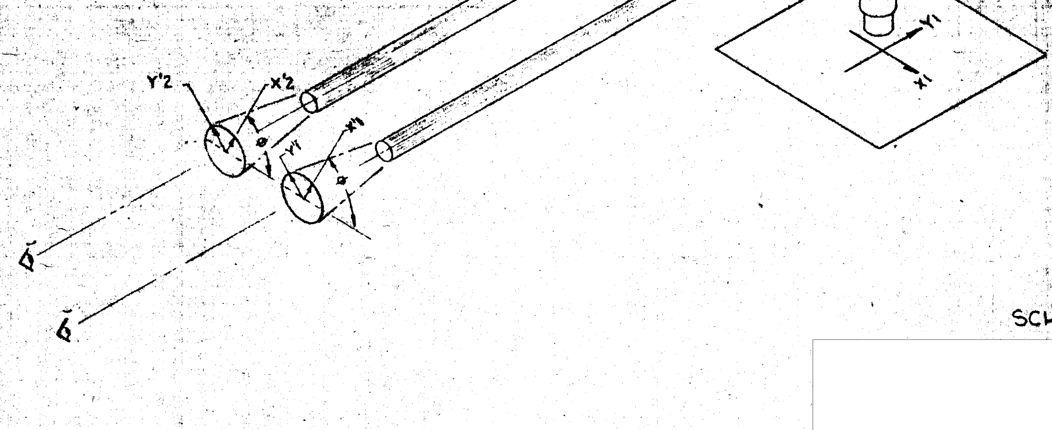

FIG. -1- SC1305
SCHEMATIC - OPTICS

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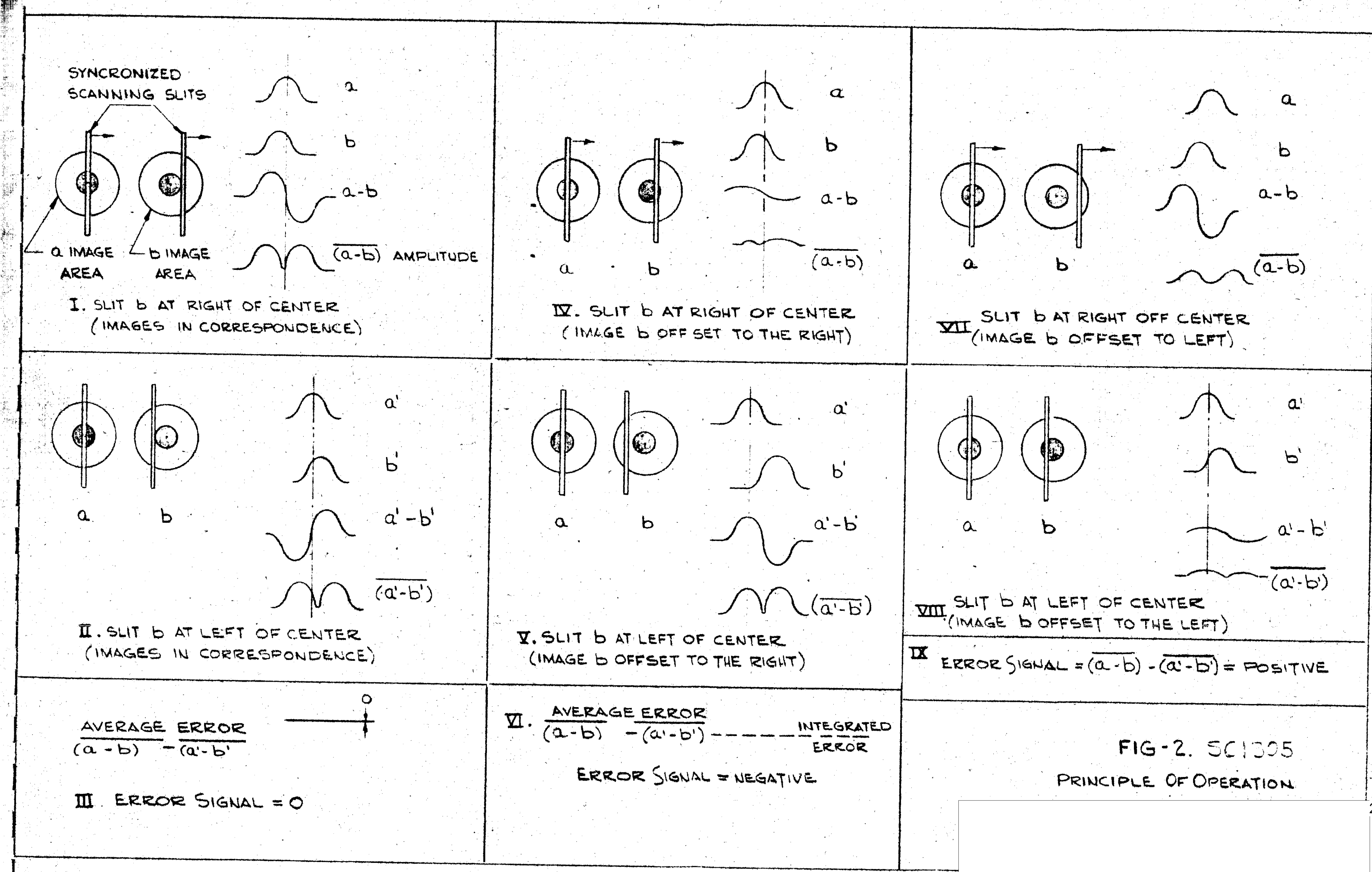

FIG-2. SC1305

PRINCIPLE OF OPERATION

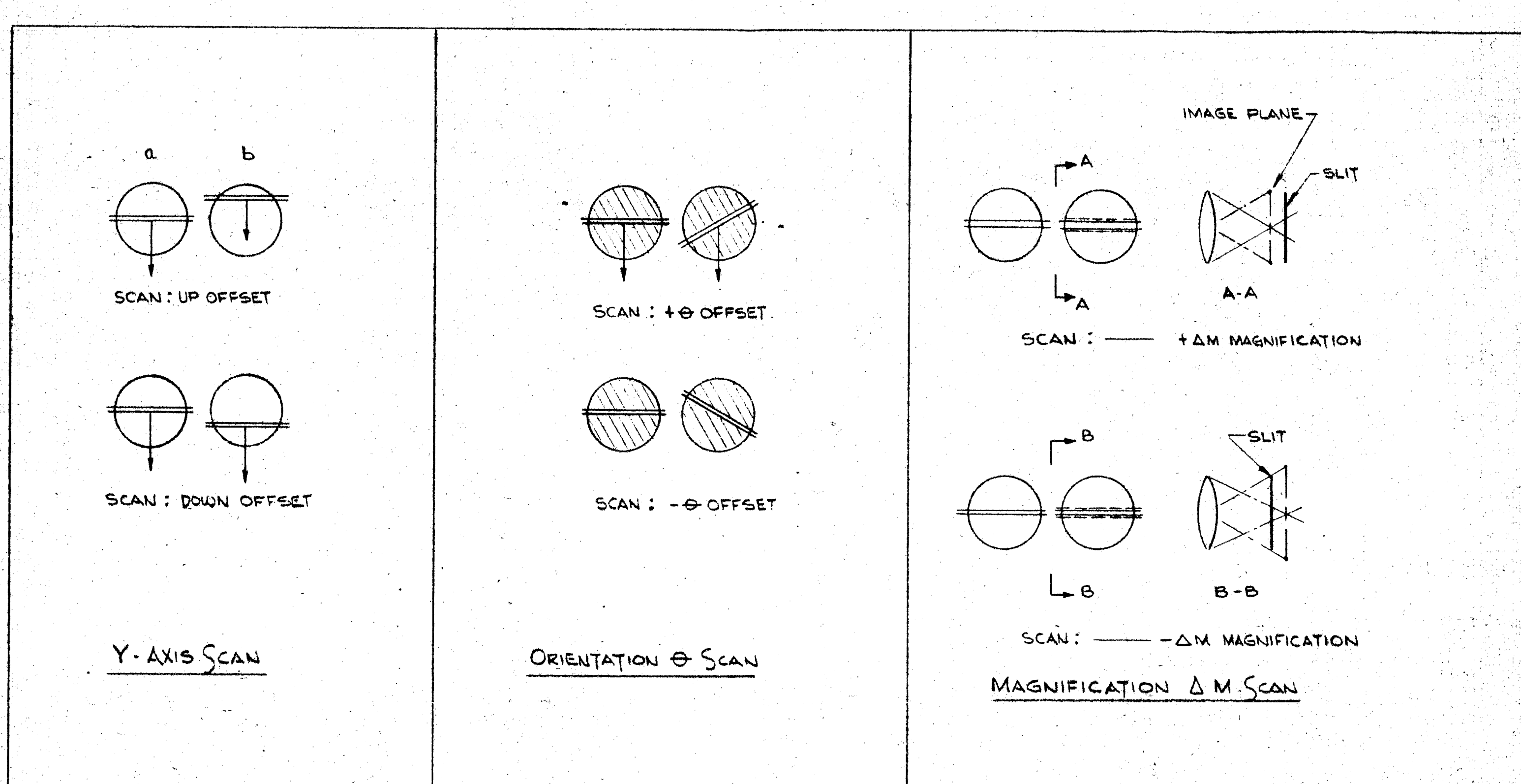

FIG. 3-SC1305

Y, θ & M SCAN

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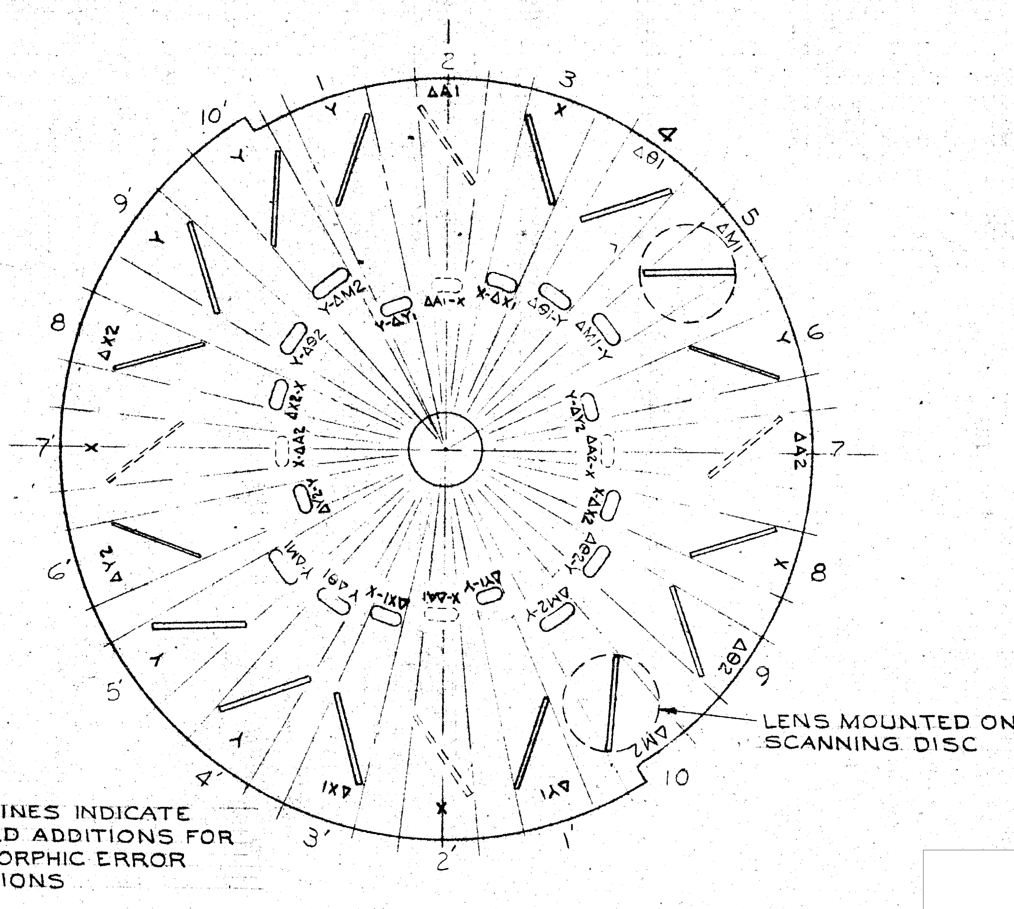

NOTE
BROKEN LINES INDICATE
PROPOSED ADDITIONS FOR
FOR ANAMORPHIC ERROR
CORRECTIONS

FIG:4 - SC1305

SCANNING DISC

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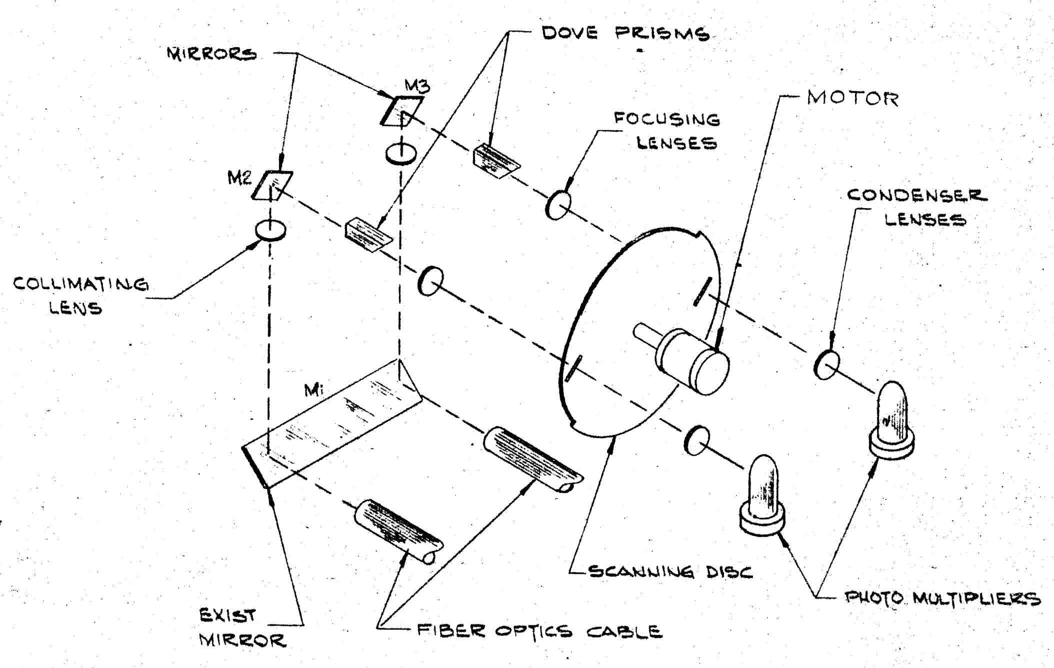

FIG.-5-SC1305

SCANNING OPTICS SCHEMATIC
AS APPLIED TO 552 TYPE VIEWER

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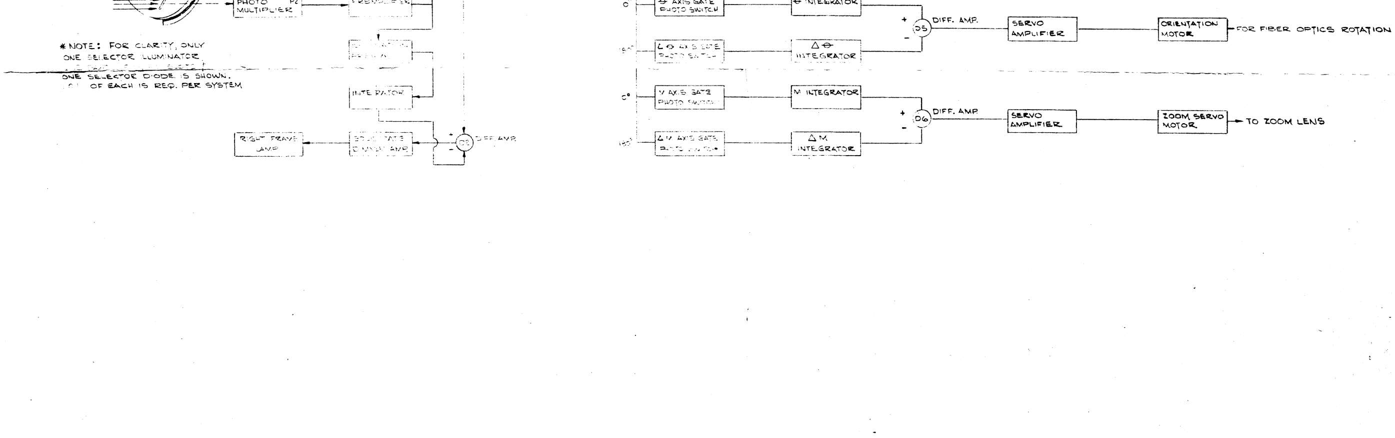

FIG. 6-SC1305
BLOCK DIAGRAM

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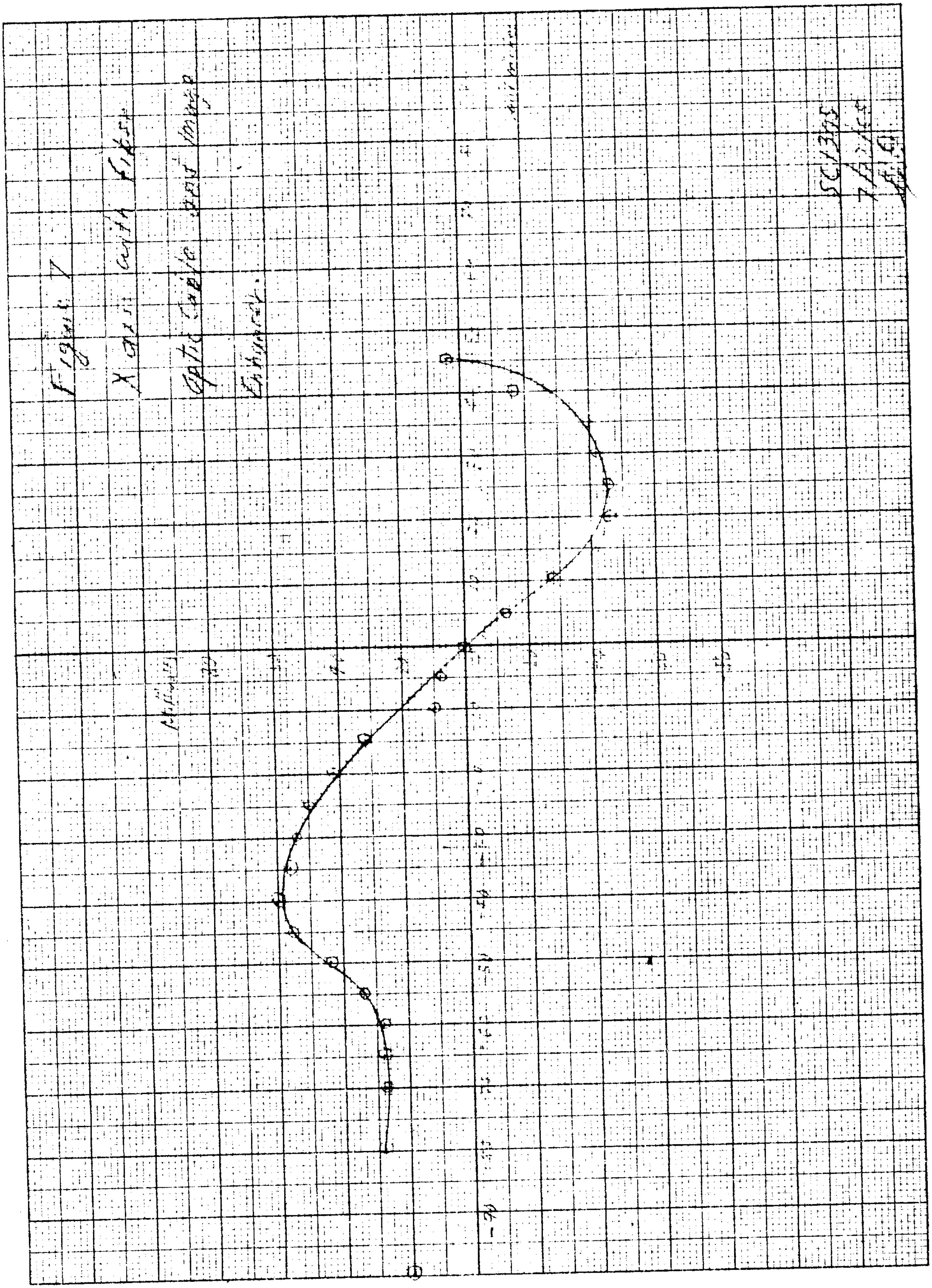

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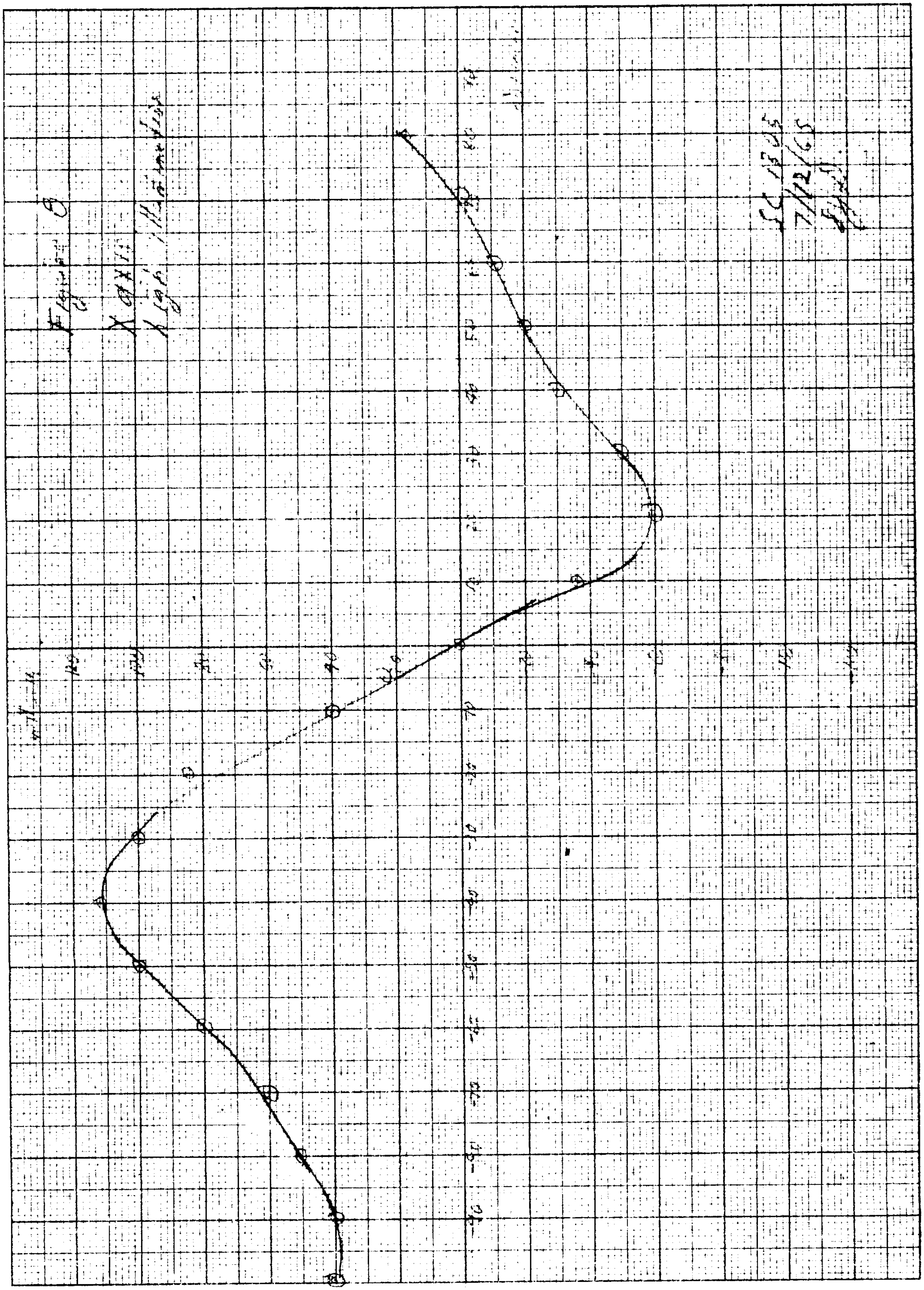

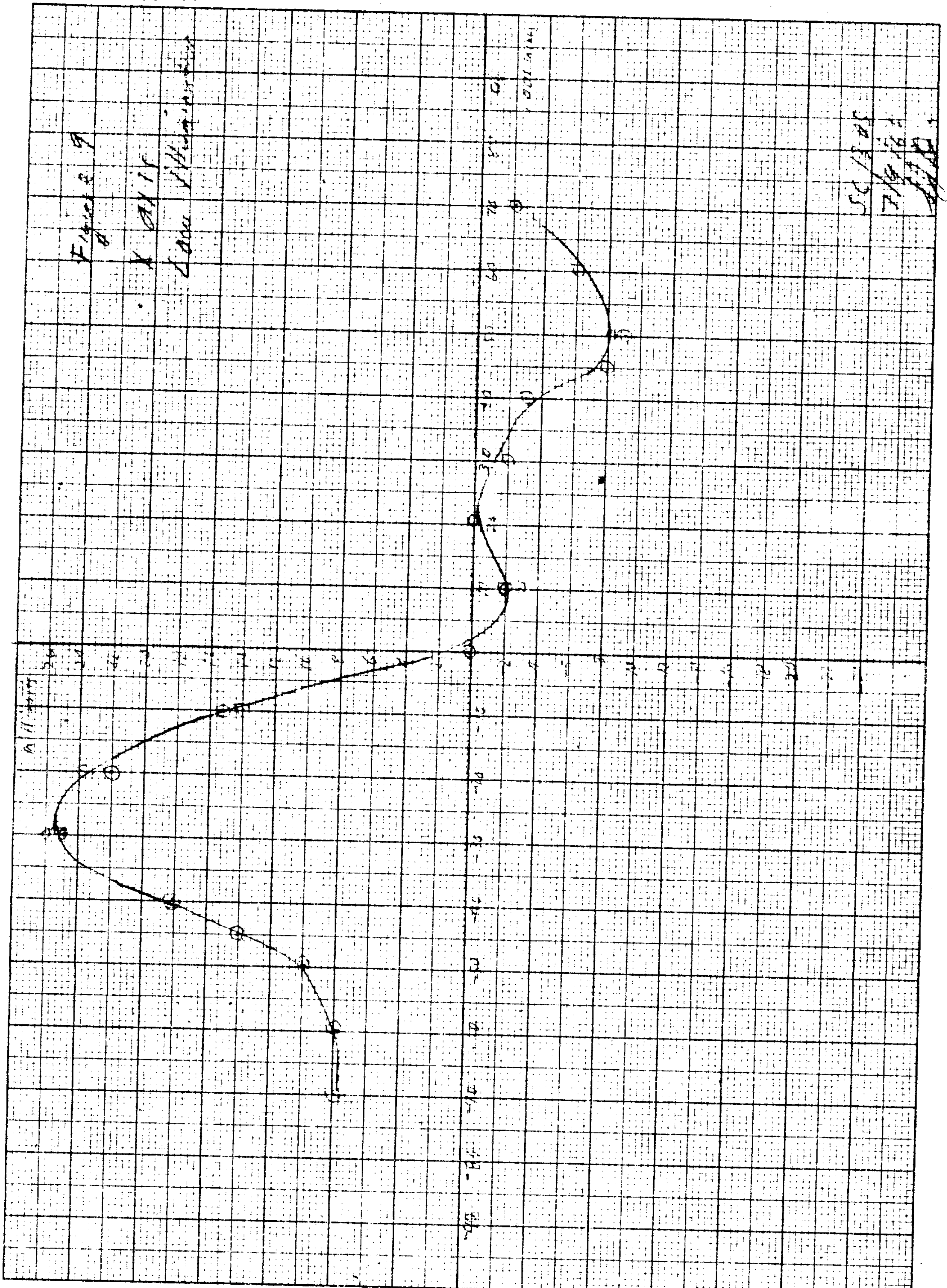

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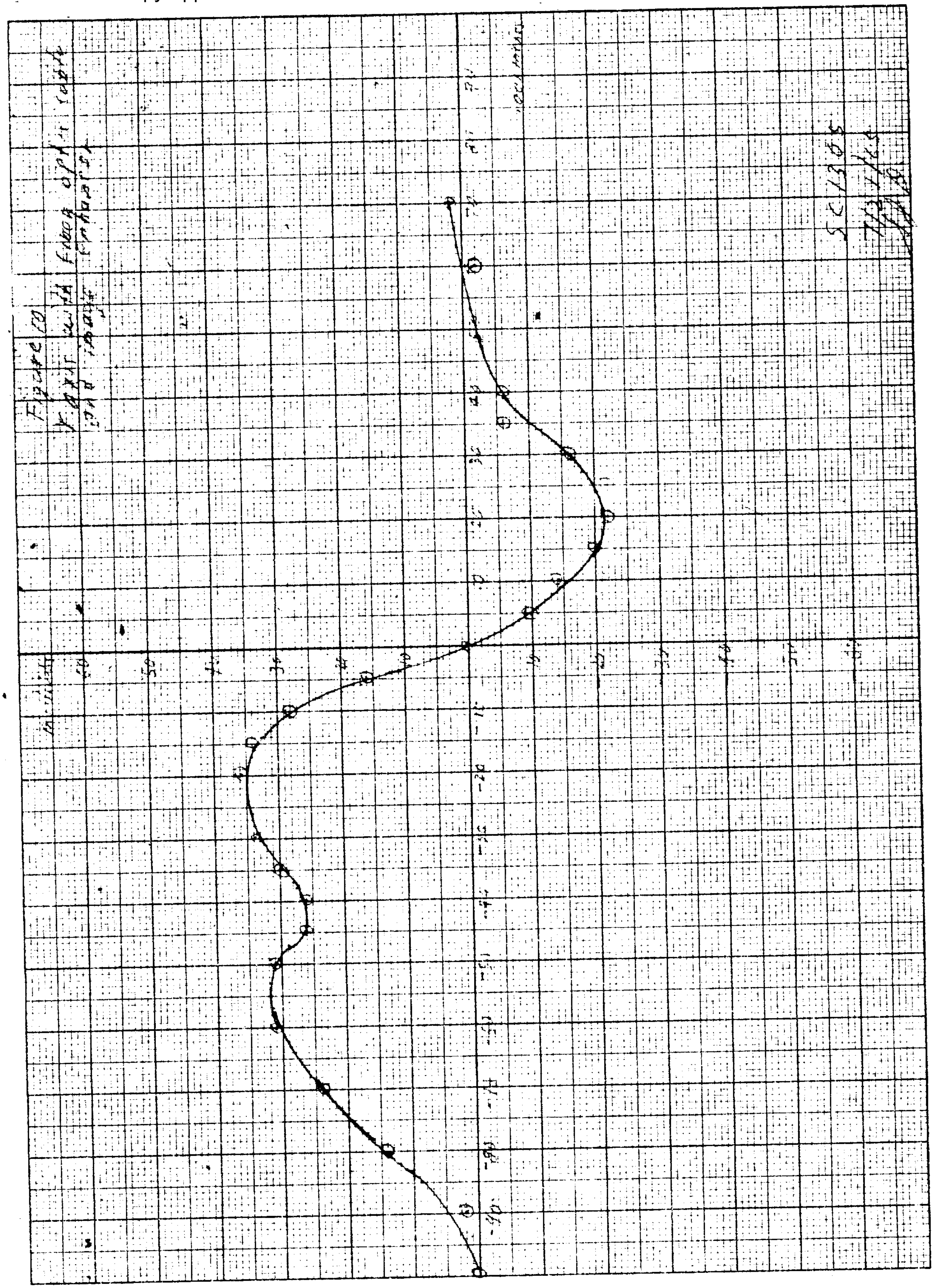

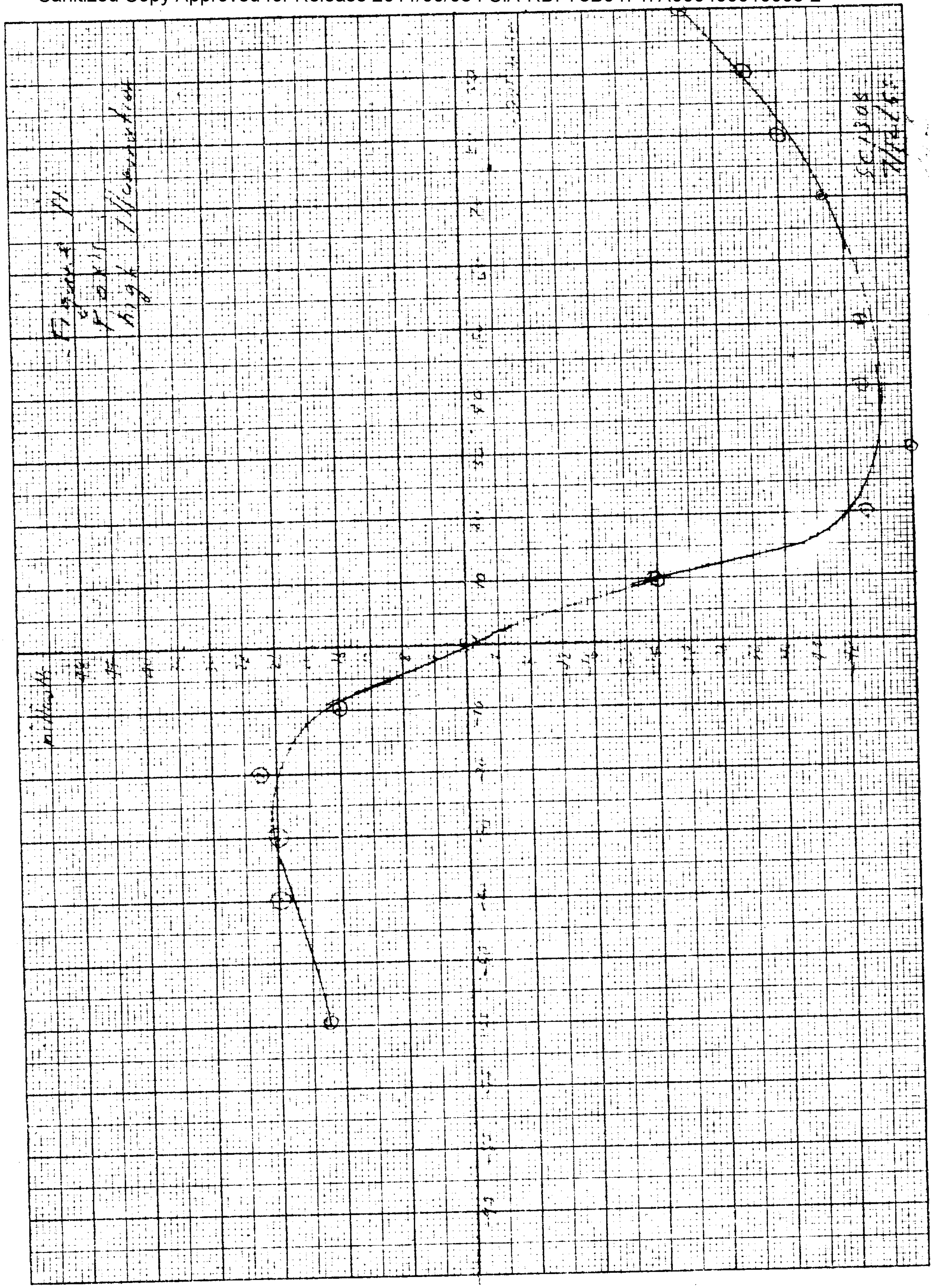

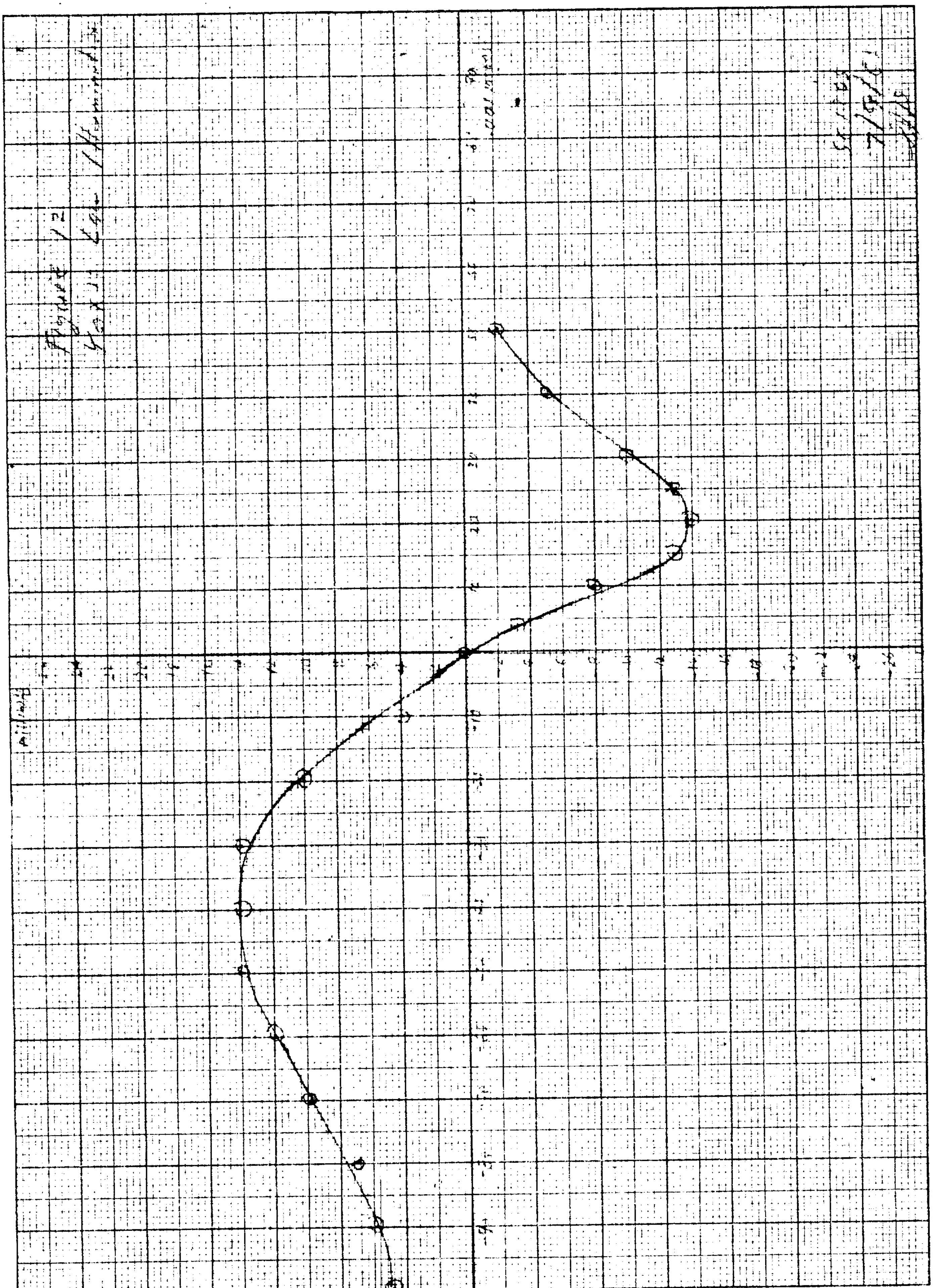

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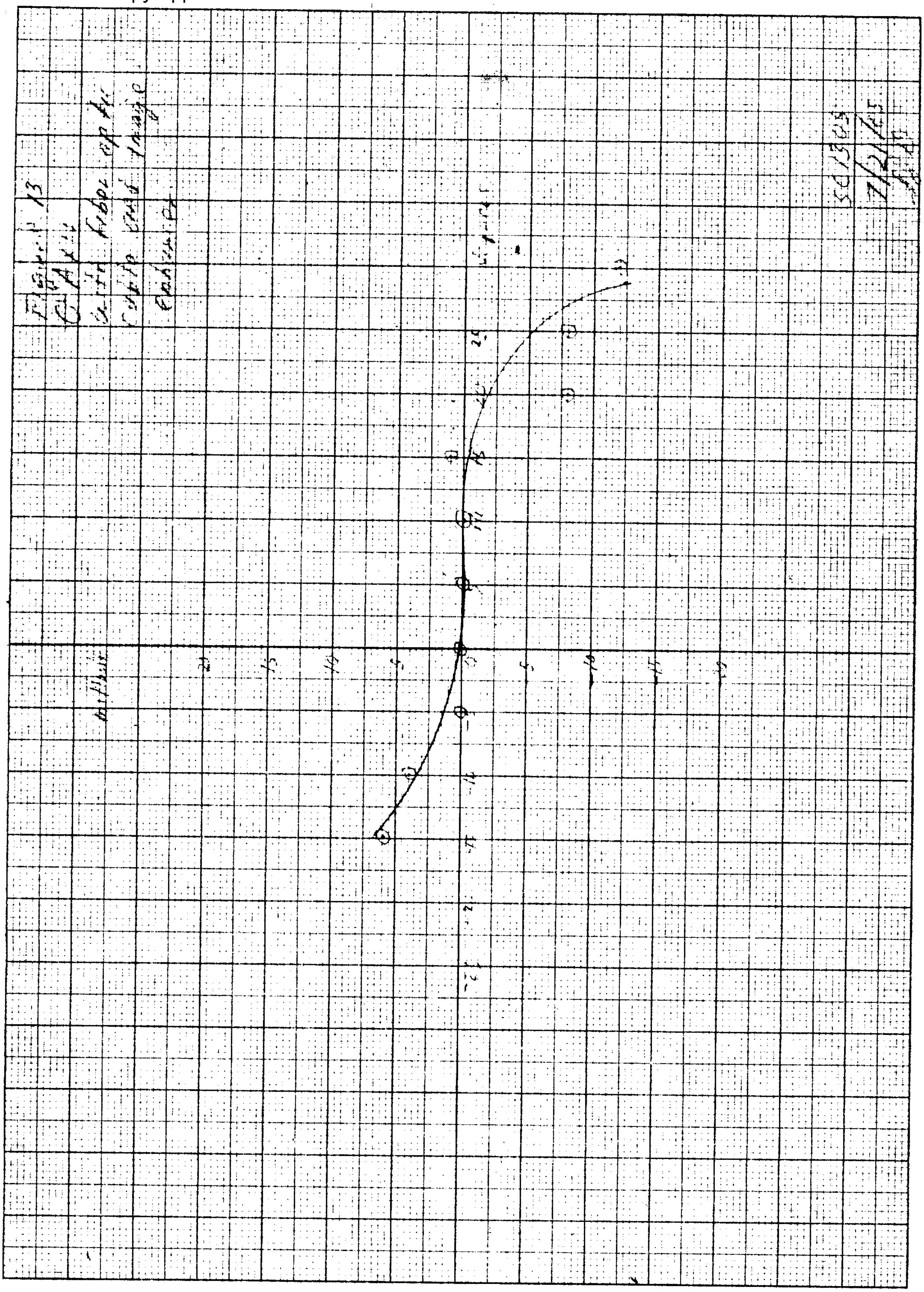


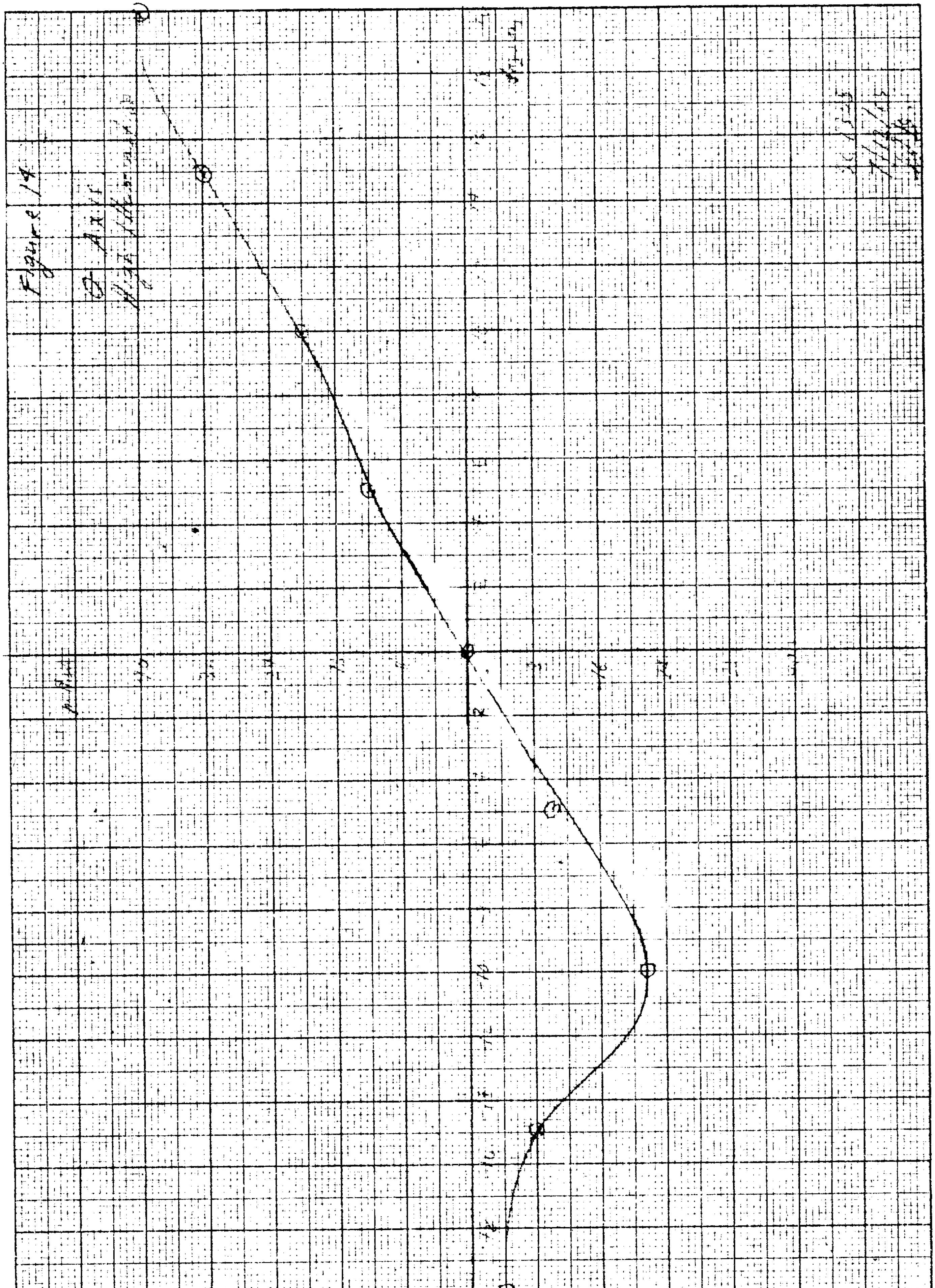
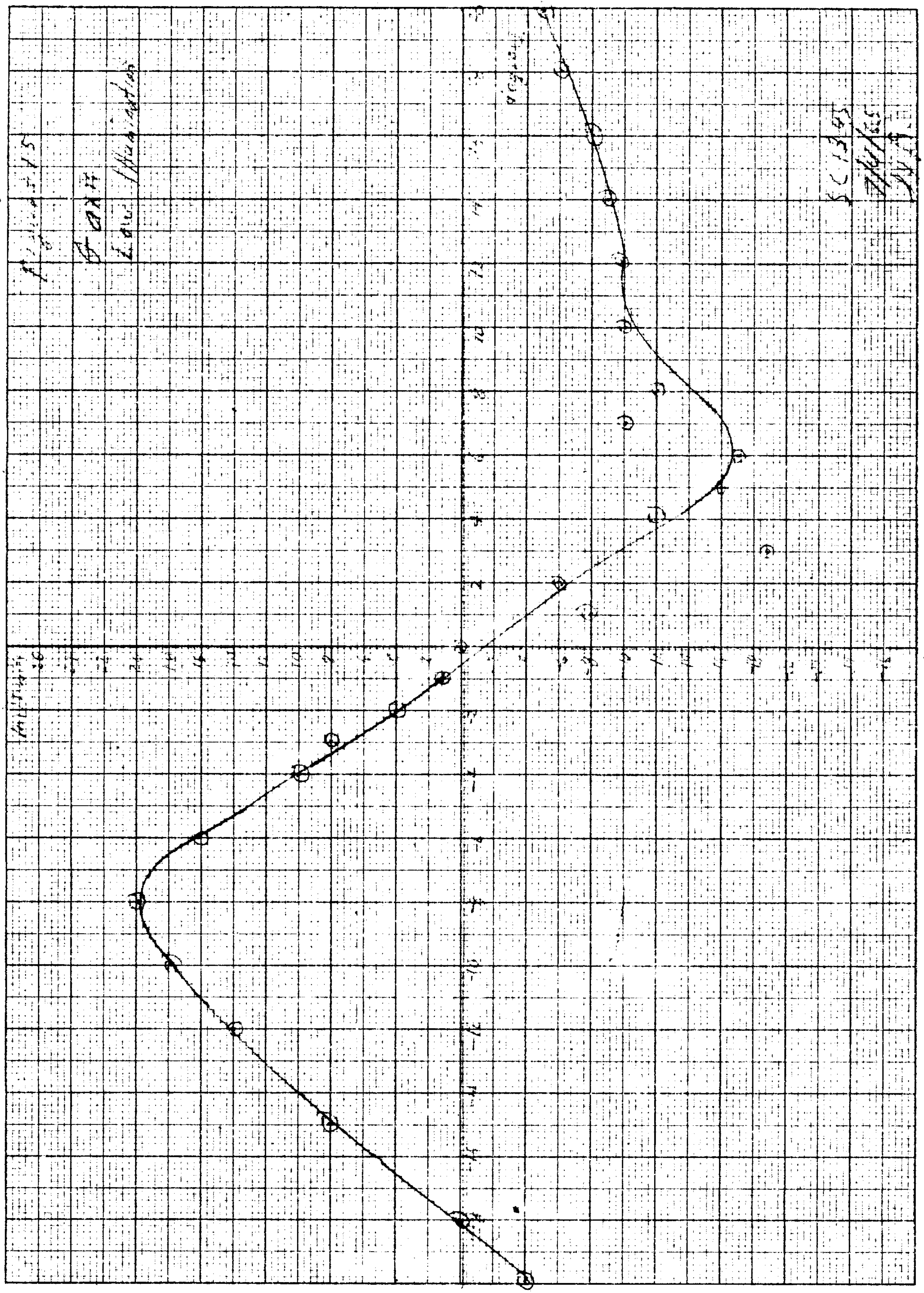


Figure 14



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